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Software for the Statistical Analysis and Display of Comparisons Between Meteorological Measuring Set Balloon Data, National Weather Service Balloon Data, and Battlescale Forecast Model Output

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13. ABSTRACT (Maximum 200 words)

A new method for the display and statistical analysis of several meteorological data types has been developed by the creation of new software in both FORTRAN and C and the use of existing FORTRAN modules as well as the GNUPLOT freeware display program. The impetus for this software development was the need for real-time on-site statistical analysis at a follow-on test of the Meteorological Measuring Set Profiler Proof-of-Concept (MMS-P (POC)) by Army Research Laboratory scientists at White Sands Missile Range, 09-20 August 1999. The MMS as it is currently fielded provides meteorological data for artillery battery aiming adjustments. Its data is derived from a weather balloon release and the subsequent tracking of the balloon and recording of the data. The next generation MMS, the MMS-P, is being developed so that rapid updates of meteorological information can occur with obvious benefit to artillery batteries that will receive the most current data for aiming adjustments. Also, it is hoped that eventually the weather balloon can be removed from the battlefield and can be replaced by a profiling suite of equipment.

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Preface

The Meteorological Measuring Set Profiler Proof-of-Concept (MMS-P (POC)) has been undergoing testing with phased improvements for the last two years. As plans were being made for the 09-20 August 1999 test/evaluation, the issue of "on-the-spot" statistical analysis of Computer-Assisted Artillery Meteorology Battlescale Forecast Model (CAAM BFM) output was raised. As no such capability existed at the time, the author incorporated into one software package: (1) existing FORTRAN interpolation routines that the author subsequently modified and (2) newly written C analysis routines and Bourne shell scripts. The interface is a menu popped up from a shell script that allows the user to compare the u- and v-components of the wind, virtual temperature, and pressure variables provided by these systems:

1. Meteorological Measuring Set (MMS) balloon data and CAAM BFM forecast data
2. MMS balloon data and National Weather Service (NWS) balloon data
3. NWS balloon data and BFM forecast data
4. Two NWS balloons
5. CAAM BFM computer meteorological message (metcm) and MMS metcm
6. Two CAAM BFM metcms

For each of these comparisons, the user has the option of sending the gnuplot graphical rendering of the data comparisons to either their computer screen or to a printer (defaults to your local printer). If the output is sent to the computer screen, the program cycles through the gnuplot displays for each of the four variable comparisons allowing each to display for approximately 10 seconds.

Preceding Pages Blank

Acknowledgments

The author would like to thank Dr. Teizi Henmi and Dr. Pat Haines of U.S. Army Research Laboratory (ARL) for their assistance in the algorithm for vertical interpolation of Computer-Assisted Artillery Meteorology Battlescale Forecast Model (CAAM BFM) pressure data. The author also wishes to credit Mr. Edward Vidal of ARL, for the C algorithm to call GNUPLOT* routines.

* Freeware graphics display package

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Executive Summary

Introduction

Software has been written in order to provide U.S. Army Research Laboratory (ARL) scientists prototyping a Meteorological Measuring Set – Profiler (Proof-of-Concept) (MMS-P (POC)) System at White Sands Missile Range with a "real-time" on-site tool to investigate the quality of, in particular, meteorological messages output by the MMS-P (POC) mesoscale model. The software consists of Bourne shell scripts, FORTRAN, C, and GNUPLOT† code. There are seven shell scripts that call on the FORTRAN and C code modules for data reformatting and processing. The GNUPLOT code modules allow for either the visual display of results or the creation of a hardcopy of the graphical results. The graphical results contain the difference between the truth data and the data being analyzed for these variables: pressure, virtual temperature, u- and v-component of the wind.

Overview

Six different types of comparisons using varying formats of meteorological data can be made. For the MMS-P (POC) testing, "truth" data is derived from two sources. They are (1) the Meteorological Measuring Set (MMS), which is an Army truck instrumented to collect meteorological data from a balloon launch. The data collected from these launches can be in either computer meteorological message (metcm) format or in a format similar to those from the National Weather Service (NWS). (2) NWS radiosonde observation (raob) collected from the Internet. The data scrutinized for accuracy during the MMS-P (POC) test were predominately the metcm's output by the Computer-Assisted Artillery Meteorology Battlescale Forecast Model (CAAM BFM) mesoscale model but occasionally the CAAM BFM binary output file containing forecasted variables was compared. Other types of comparisons can be made as well. The user has the options listed below.

1. MMS balloon data versus CAAM BFM forecast data (binary file)
2. MMS balloon data versus NWS format balloon data
3. NWS format balloon data versus CAAM BFM forecast data

† Freeware graphics display package

4. NWS format balloon data versus like data (temporally and/or spatially displaced)

5. CAAM BFM (computer meteorological message [metcm]); American Standard Code for Information Interchange [ASCII] file) versus MMS metcm

6. CAAM BFM metcm versus like data (temporally and/or spatially displaced)

All of the interpolation, both horizontal and vertical takes place within the FORTRAN modules. The C modules handle the parsing of data files and the derivation of statistics.

Conclusions

Based on preliminary testing, this software has proven to be beneficial in determining the quality of meteorological data output by CAAM BFM both during and after MMS-P (POC) testing.

A new method for the display and statistical analysis of several meteorological data types has been developed by the creation of new software in both FORTRAN and C and the use of existing FORTRAN modules as well as the GNUPLOT freeware display program. The impetus for this software development was the need for real-time on-site statistical analysis at a follow-on test of the MMS-P (POC) by ARL scientists at White Sands Missile Range, NM 9–20 August 1999. The MMS as it is currently fielded provides meteorological data for artillery battery aiming adjustments. Its data is derived from a weather balloon release and the subsequent tracking of the balloon and recording of the data. The next generation MMS, the MMS-P, is being developed so that rapid updates of meteorological information can occur with obvious benefit to artillery batteries that will receive the most current data for aiming adjustments. In addition, it is hoped that eventually the weather balloon can be removed from the battlefield and can be replaced by a profiling suite of equipment.

1.0 Overview

There were two key parts to this Meteorological Measuring Set – Profiler (Proof-of-Concept) MMS-P (POC) test. The first is to verify the interoperability of all hardware components including a radar, radiometer, surface sensor, satellite receiver, as well as several computer servers for data communication. The second is to ascertain the accuracy of the meteorological mesoscale forecasting model output when profiler data from MMS-P (POC) is used as one of the inputs. The model for MMS-P (POC) is the Computer-Assisted Artillery Meteorology Battlescale Forecast Model (CAAM BFM). It is a hydrostatic model capable of providing 12-hour forecasts and yields two outputs that are of relevance to this software development. They are the computer meteorological message (metcm) and the binary output (out.bin) file, which contains, among other things, the u- and v-components of the wind, ambient temperature, and mixing ratio. The metcm is specifically tailored for the needs of the artillery and is a 27-line message containing data from the surface up to 20-km above ground level (AGL). At each metcm level are the level number and four variables: wind direction (tens of mils), wind speed (kt), virtual temperature (K), and pressure (mb). The mil is a unit particular to artillery. To convert from mils to degrees one multiplies by the factor, 360°/6400 mils.

In order to determine the accuracy of CAAM BFM output, some data sets had to be chosen as "truth". For this particular MMS-P (POC) test at White Sands Missile Range, Meteorological Measuring Set (MMS) weather balloons were launched quite often in the proximity of the MMS-P (POC) equipment. Also, data from the weather balloon launched at Santa Teresa, NM (near El Paso, TX) was available for all but one day of the experiment soon after launches at 0000 Universal Time Coordinates (UTC) and 1200 UTC. Also noteworthy is that within each MMS message the data can be found in two different formats and are not identical data sets. One format is the same type used by the National Weather Service (NWS) that reports "point" measurements of temperature, wind, and moisture parameters at the so-called "mandatory" levels plus "significant" levels. The other is the metcm where the wind and temperature are reported as an average over a particular height range with pressure being the only reported point measurement. In addition, the format of the NWS weather balloon data posted at various Internet sites varies somewhat. Specifically, sometimes the reports contain a line listing the station elevation and sometimes this is absent. In addition,

some reports will occasionally report pressure to a tenth of a millibar rather than as a simple integer. Thus, the analysis software was designed to handle these variable formats and to be flexible enough to allow the user to compare any of the data types discussed above. In addition, so that the user could easily visualize the results of a given comparison, GNUPLOT‡ was adopted, primarily due to the author's familiarity with it.

‡ Freeware graphics display package

2.0 Statistical Analysis

Because the CAAM BFM data is gridded data, bilinear interpolation is a practical means of interpolating horizontally to a particular point, in this case, to the latitude/longitude of the MMS-P (POC) experimental site at White Sands Missile Range. For 8 of the 12 options available to the user, vertical interpolation to fixed heights mean sea level (MSL) is carried out so those variables from two vertical profiles are compared at the same heights. There are only six distinct types actually; however, since there are print/display options for each type, the user will have 12 choices. The four types which involve vertical interpolation are comparisons between: 1) MMS radiosonde observation (raob), model 2) MMS raob, NWS format raob 3) NWS format raob, model and 4) 2 NWS format raobs. Simple linear interpolation in the vertical can be carried out for the u- and v-components and for virtual temperature. However, for pressure, the hypsometric relationship (which states essentially that pressure decreases exponentially with height) is used. This horizontal and vertical interpolation is carried out in three FORTRAN programs.

1. compare_raob1_raob2.f

For the case of a comparison between two NWS format raobs.

2. compare_raob_BFMout_bin.f

For the case of NWS format raob and model data comparison.

3. compare_raob_MMSraob.f

For the case of MMS raob and NWS format raob comparison.

When a MMS raob is used, the C program parseMMS.c must be called. MMS messages contain both a vertical profile like that from a raob from the NWS and the same data in a metcm format plus lots of other extraneous information. parseMMS looks for and extracts the NWS format-sounding portion of the MMS message. Similarly, when a raob such as those from the NWS is used, the C program, parseInternetRaob.c extracts the appropriate data.

The C program rd_raob_compare.c, using the output from these FORTRAN programs, then checks for missing values and calculates the root mean square error (rmse) for the u- and v-components, virtual temperature, and pressure.

There are two comparison types in which no vertical interpolation is done:

1. CAAM BFM metcm, MMS metcm
2. CAAM BFM metcm, CAAM BFM metcm.

For CAAM BFM metcm's, the C program, reformat_bfm_metcm_to_columns is called. For MMS metcm's, the C program, reformat_mms_metcm_to_columns is called. The latter is much more complex as it must search for patterns within the MMS message to extract only the metcm portion. The deltas between variables and rmse values for u, v, Tv and P are then calculated by the C programs, compare_mms_bfm_metcm or compare_bfm1_bfm2_metcm depending on the option selection. It is emphasized that if one is going to use either of these two options that the two stations being compared have only minor surface elevation differences and preferably no major topographic features intervening such as mountains.

Seven scripts control the entire statistical analysis and display/print process. The primary script is called "stats" and it in turn calls one of the other six scripts depending on user response to queries. The six types of comparisons that the user has to choose from and the respective controlling scripts are listed below.

1. MMS balloon data compared to CAAM BFM out.bin data

MMSraob_model.sh

2. MMS balloon data compared to NWS format balloon data

MMSraob_raob.sh

3. NWS format balloon data compared to CAAM BFM out.bin data

raob_model.sh

4. NWS format balloon data compared to NWS format balloon data for another site/time

raob_raob.sh

5. A CAAM BFM metcm compared to a MMS metcm

caam-metcm_mms-metcm.sh

6. A CAAM BFM metcm for one location compared to a CAAM BFM metcm for another location

bfm-metcm_bfm-metcm.sh

For each of these six cases, the user has the option of viewing the graphical results through GNUPLOT or sending the graphical results to

the computer's default printer (which must have postscript printing capability) after a postscript file has been created (by GNUPLOT). When the user chooses the display option, they will see popping up on their screen respectively, plots of the u-component of the wind, v-component of the wind, virtual temperature, and pressure. Each plot will display for 15 seconds before giving way to the next plot. The time each display is on the screen is controlled in C code that makes GNUPLOT calls (see Appendix C for an example). The GNUPLOT files are set to "autoscale" in both the x- and y-directions. When the user chooses the print option, a postscript file is created and automatically printed to the default printer for the computer they are utilizing (thus the user must be cognizant of which printer that is). In addition, regardless of the option chosen, the root mean square error for the u- and v-components of the wind, virtual temperature, and pressure will be printed to the screen.

Figure 1 is the initial stats menu.

Figure 1. Initial stats menu.

```
Make a selection from these choices:
   1. Compare MMS raob with BFM out.bin data and display results
   2. Compare MMS raob with BFM out.bin data and send results to printer
   3. Compare MMS raob with a raob and display results
   4. Compare MMS raob with a raob and send results to printer
   5. Compare a raob with BFM out.bin data and display results
   6. Compare a raob with BFM out.bin data and send results to printer
   7. Compare a raob with another raob and display results
   8. Compare a raob with another raob and send results to printer
   9. Compare a CAAMBFM metcm to a MMS metcm and display results
  10. Compare a CAAMBFM metcm to a MMS metcm and send results to printer
  11. Compare 2 CAAMBFM metcm's and display results
  12. Compare 2 CAAMBFM metcm's and send results to printer
  13. Quit the analysis and display/print program
```

Error handling is built into the stats script. For example, if the user selects outside the range 1-13 they will see a message indicating the problem and how to rectify it. The following graphic (figure 2) is an example of an invalid choice.

Figure 2. Result of user making an invalid selection in stats.

```
 10. Compare a CAAMBFM metcm to a MMS metcm and send results to printer
 11. Compare 2 CAAMBFM metcm's and display results
 12. Compare 2 CAAMBFM metcm's and send results to printer
 13. Quit the analysis and display/print program

0

0 is not a valid choice (must be in range 1-13)

Make a selection from these choices:
  1. Compare MMS raob with BFM out.bin data and display results
  2. Compare MMS raob with BFM out.bin data and send results to printer
  3. Compare MMS raob with a raob and display results
  4. Compare MMS raob with a raob and send results to printer
  5. Compare a raob with BFM out.bin data and display results
  6. Compare a raob with BFM out.bin data and send results to printer
  7. Compare a raob with another raob and display results
  8. Compare a raob with another raob and send results to printer
  9. Compare a CAAMBFM metcm to a MMS metcm and display results
 10. Compare a CAAMBFM metcm to a MMS metcm and send results to printer
 11. Compare 2 CAAMBFM metcm's and display results
 12. Compare 2 CAAMBFM metcm's and send results to printer
 13. Quit the analysis and display/print program
```

Figure 3 shows what the user will see when they select option 1 (or option 2). Since the CAAM BFM mesoscale model always outputs the file generically named out.bin, this is the name the stats program expects to see when model comparisons are to be done. What the user will need to know about the model run is how many hours of forecast were done. They then will be able to index to the particular forecast hour of interest by giving that value as in figure 3. Here the user has chosen the first hour of the forecast. In addition, the user will be asked for a MMS balloon file name. (Note: the reader will see in upcoming graphics the phrase "raob", in other words the balloon data is picked up at the ground via telemetry.)

Figure 3. Option 1 query.

```
Make a selection from these choices:
  1. Compare MMS raob with BFM out.bin data and display results
  2. Compare MMS raob with BFM out.bin data and send results to printer
  3. Compare MMS raob with a raob and display results
  4. Compare MMS raob with a raob and send results to printer
  5. Compare a raob with BFM out.bin data and display results
  6. Compare a raob with BFM out.bin data and send results to printer
  7. Compare a raob with another raob and display results
  8. Compare a raob with another raob and send results to printer
  9. Compare a CAAMBFM metcm to a MMS metcm and display results
 10. Compare a CAAMBFM metcm to a MMS metcm and send results to printer
 11. Compare 2 CAAMBFM metcm's and display results
 12. Compare 2 CAAMBFM metcm's and send results to printer
 13. Quit the analysis and display/print program

1
enter MMS raob file name (the BFM file is assumed to be named out.bin)
99081616.txt
enter the forecast hour you want
1
```

3.0 Case Results

3.1 Comparison of MMS Balloon Data with CAAM BFM Model Data at a Particular Latitude/Longitude

For figures 4-7, the MMS data is from a balloon launch at the MMS-P (POC) profiler test site on 16 August 1999 at 2200 UTC. The model run is valid for 16 August 1999, 2000 UTC. In the u-component comparison, one can see that in the lower 2 km, that the model indicates a weaker westerly component. At 5 km, the situation is reversed. For the v-component, the graph indicates the model has a stronger southerly component near the surface, by about 3 m/s with the situation reversing again at higher altitudes. For the virtual temperature comparison in figure 6, the model is overestimating surface temperature by almost 4° K. This overestimation of temperature near the surface is a known current CAAM BFM model problem and is being investigated. For pressure there is fairly good agreement at all levels except at 1 km and above 7 km. In the BFM model, the levels for pressure and temperature are distinct. For each pressure interpolation level, the pressure at the level below and the mean temperature for the layer are involved. As these two variables are defined at different height levels, the interpolation becomes quite convoluted. It may be possible to improve the pressure interpolation slightly. Dr. Henmi, ARL, has suggested considering interpolating the pressure downward and/or taking the pressure change with height at the center of each grid point as the average of the pressure change with height at the four surrounding grid points.

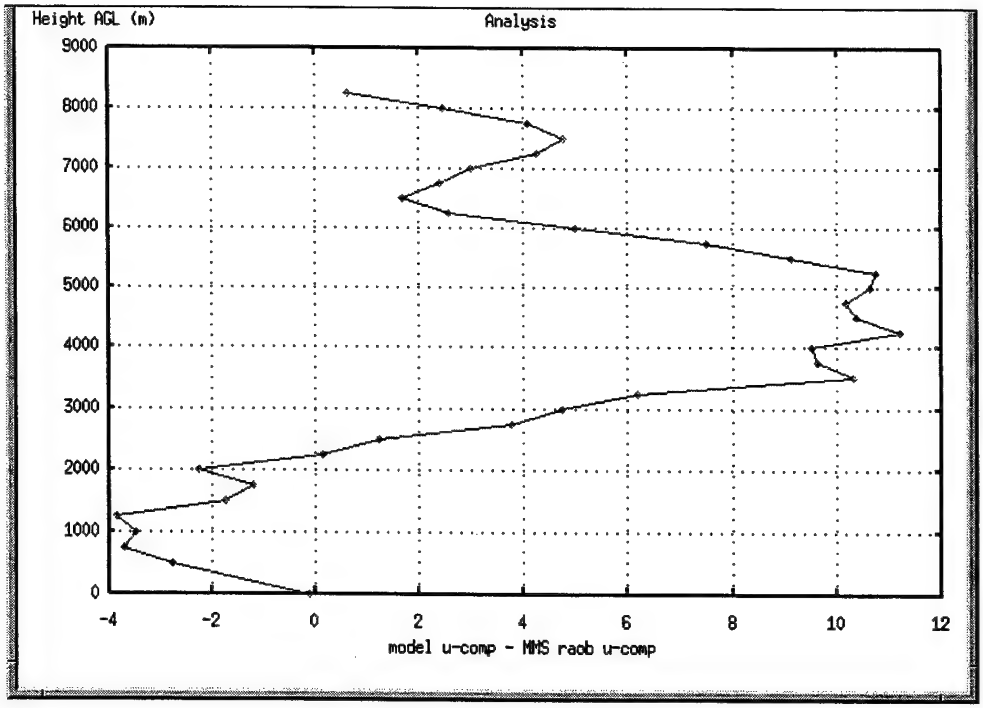


Figure 4. MMS raob for Profiler site (16 August 1999, 2200 UTC), model "profile" for Profiler site (valid 16 August 1999, 2000 UTC) u-component deltas (m/s).

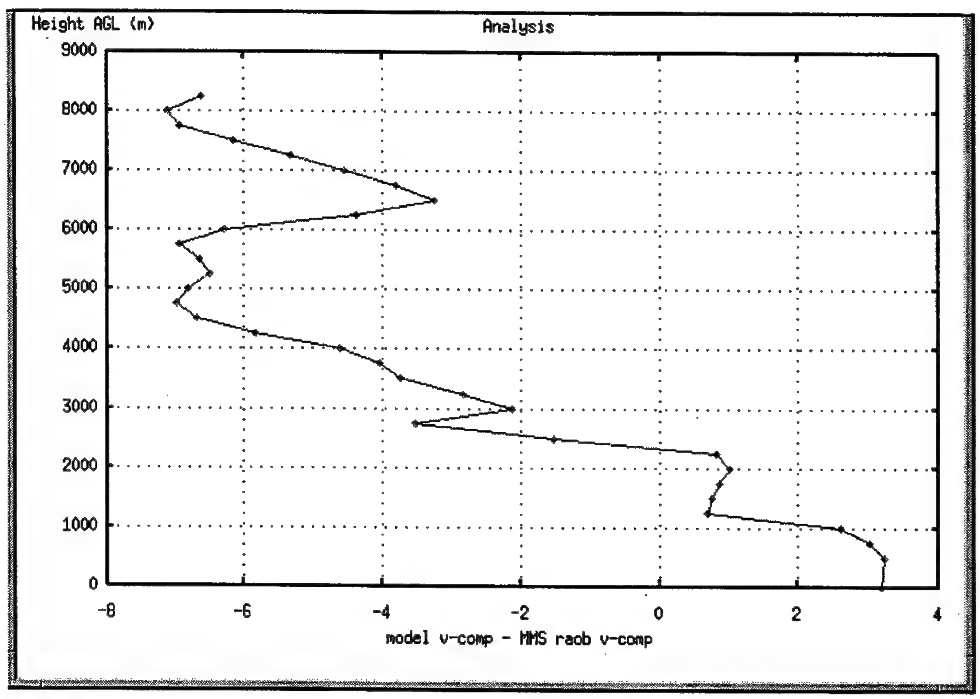


Figure 5. MMS raob for Profiler site (16 August 1999, 2200 UTC), model "profile" for Profiler site (valid 16 August 1999, 2000 UTC) v-component deltas (m/s).

Figure 6. MMS raob for Profiler site (16 August 1999, 2200 UTC), model "profile" for Profiler site (valid 16 August 1999, 2000 UTC) Tv deltas (deg K).

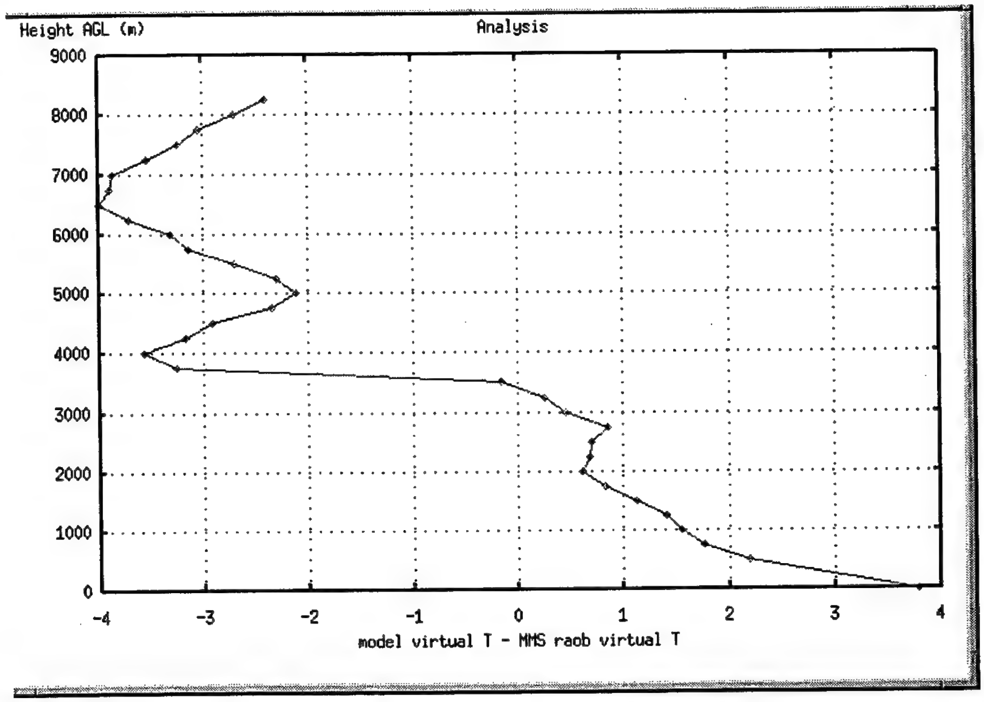
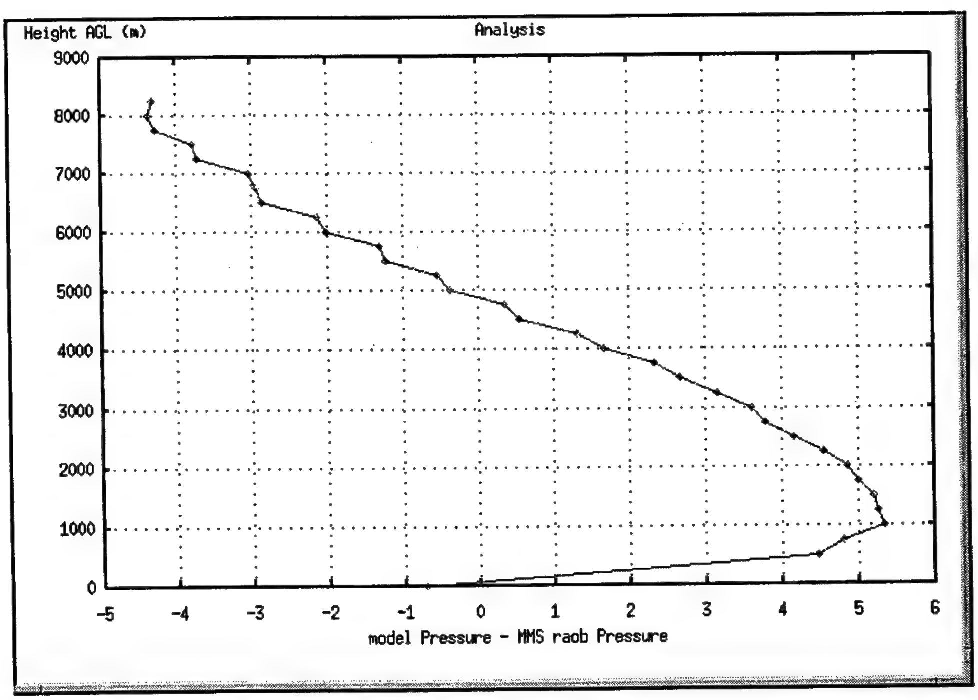


Figure 7. MMS raob at Profiler site (16 August 1999, 2200 UTC), model "profile" for Profiler site (valid 16 August 1999, 2000 UTC) P deltas (mb).

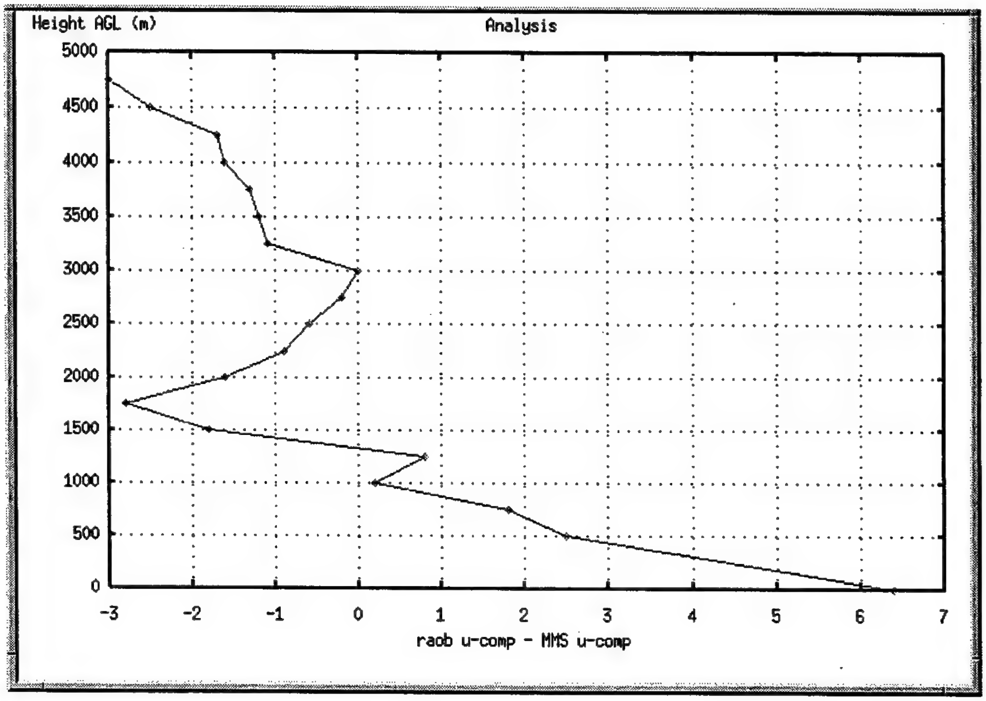


3.2 Comparison of MMS Balloon Data with NWS Format Balloon Data

In this case vertical interpolation to fixed heights mean sea level (MSL) is carried out for all the variables (u, v, Tv, and P) for both the MMS balloon and the NWS format balloon data.

Figure 8 shows the u-component differences for the NWS raob and MMS raob. At the surface the Santa Teresa raob, which was taken 2 h later than the MMS raob, shows stronger westerlies at the surface.

Figure 8. MMS raob at Profiler site (10 August 1999, 2200 UTC) and Santa Teresa, NM raob (11 August 1999, 0000 UTC) u-component comparison (m/s).



The v-component differences are shown in Figure 9. The MMS raob indicates a stronger southerly component at the surface. Above 1.5 km, the two systems agree fairly well.

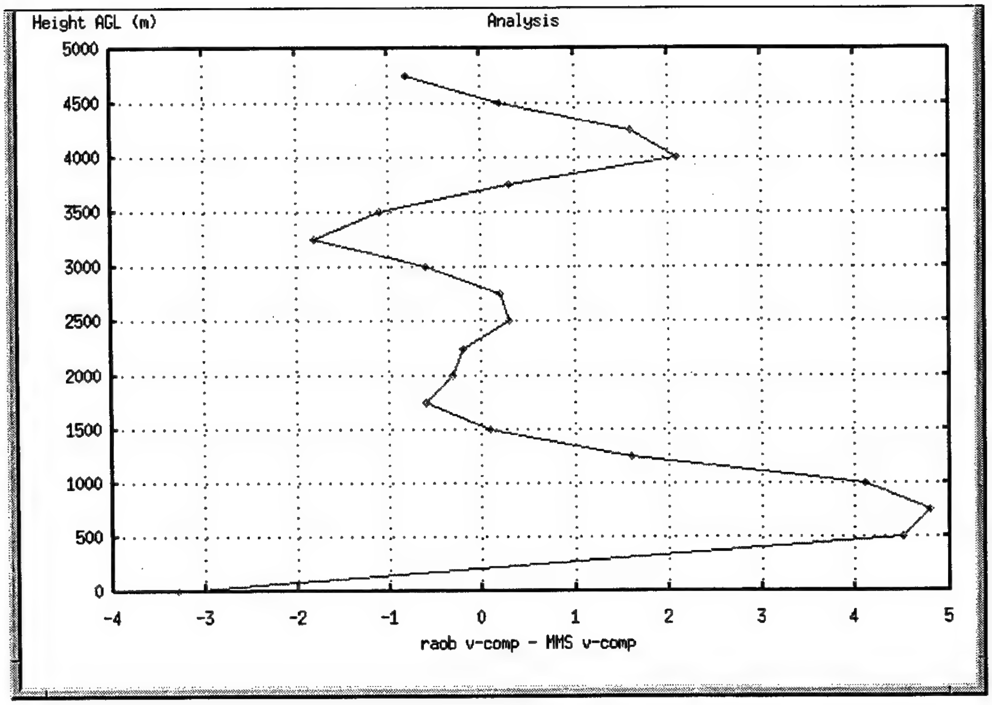


Figure 9. MMS raob at Profiler site (10 August 1999, 2200 UTC) and Santa Teresa, NM raob (11 August 1999, 0000 UTC) v-component comparison (m/s).

Figure 10 shows the virtual temperature differences. The earlier launch of the MMS raob (1600 local time) accounts for the warmer MMS surface virtual temperature. Overall, the differences are small.

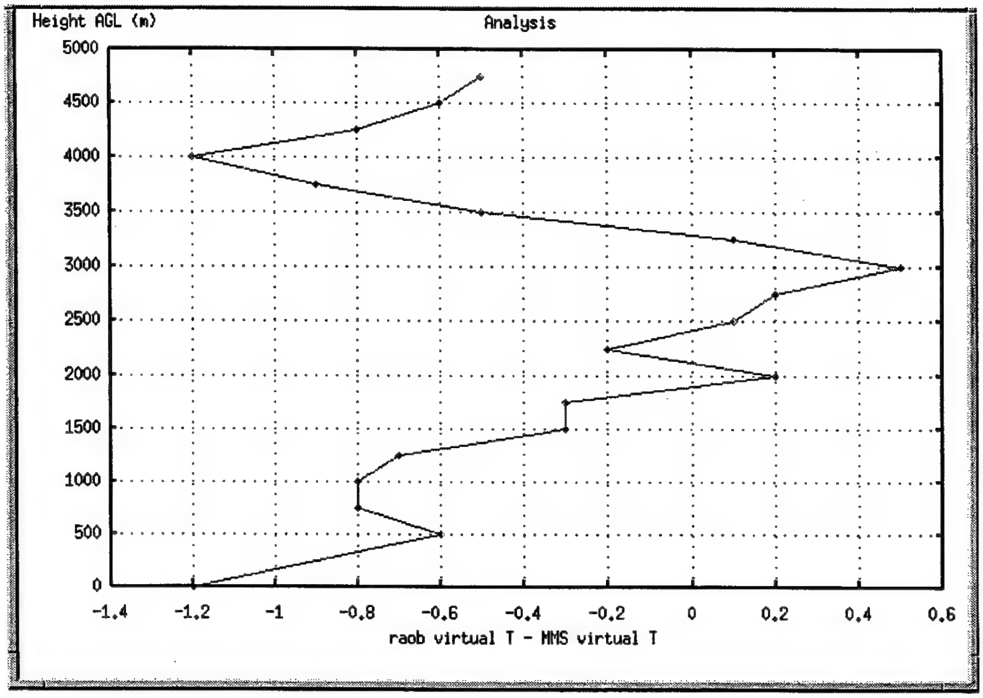
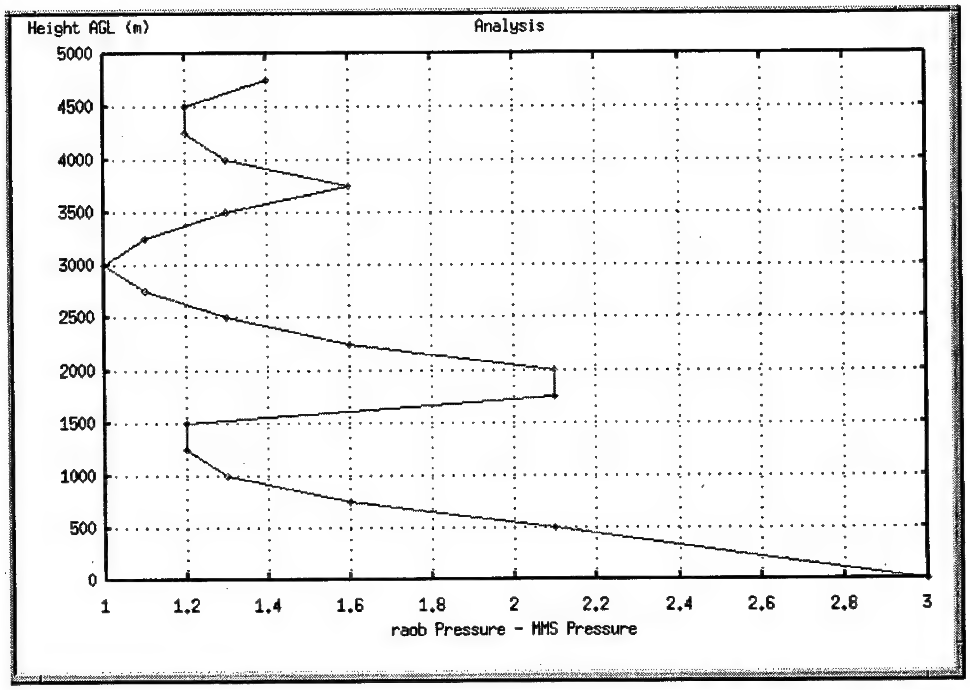


Figure 10. MMS raob at Profiler site (10 August 1999, 2200 UTC) and Santa Teresa, NM raob (11 August 1999, 0000 UTC) Tv comparison (deg K).

Pressure differences are displayed in figure 11. At the surface, the raob pressure is slightly higher which makes sense as part of the diurnal pressure cycle. As the temperatures cool, air density increases leading to an increase in pressure. A fraction of the difference is also attributable to the raob launch site being about 13 m lower than the MMS launch site.

Figure 11. MMS raob at Profiler site (10 August 1999, 2200 UTC) and Santa Teresa, NM raob (11 August 1999, 0000 UTC) P comparison (mb).



3.3 Comparisons of NWS Format Balloon Data with like Data Displaced Either Spatially or Temporally or Both.

Figures 12–15 show the deltas for u, v, Tv, and P for 9 and 10 August 1999, 1200 UTC raobs taken at Santa Teresa, NM. Note in figure 13, the 10 August 1999 raob indicates significantly stronger southerly flow. Above 2 km, the two raobs show only minor differences as one typically gets under the weak flow of a ridge in summer. Figure 14 shows the 10 August raob indicating a temperature 2.5 C ° K warmer at the surface and 2° K cooler at 2 km. Above that, agreement is good—roughly within a degree.

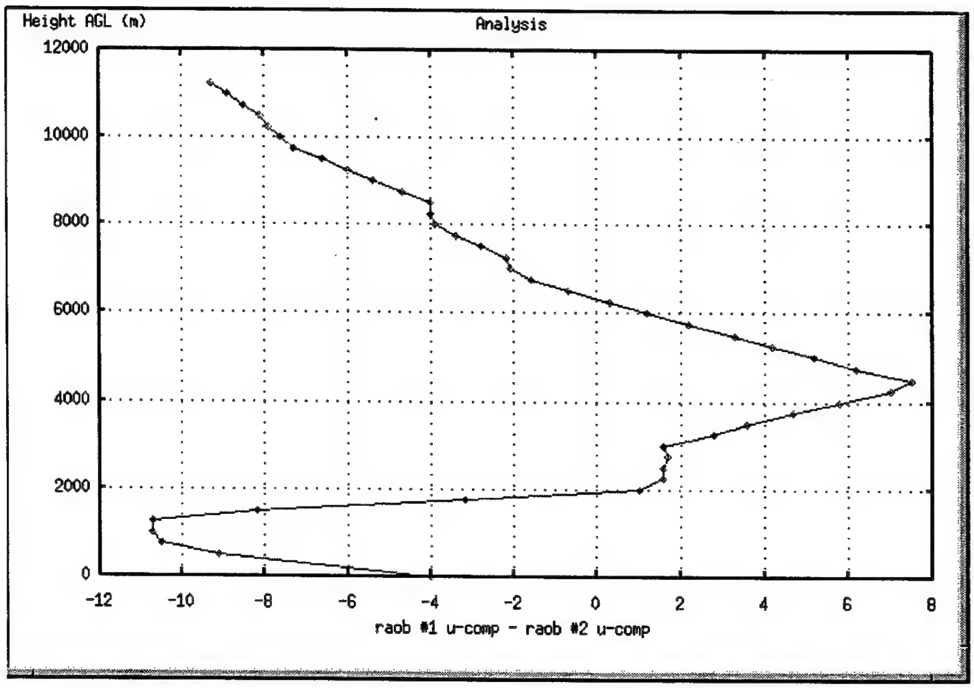


Figure 12. U-component deltas (m/s) for two 1200 UTC Santa Teresa, NM raobs, 9 August and 10 August 1999.

Figure 13. V-component deltas (m/s) for two 1200 UTC Santa Teresa, NM raobs, 9 August and 10 August 1999.

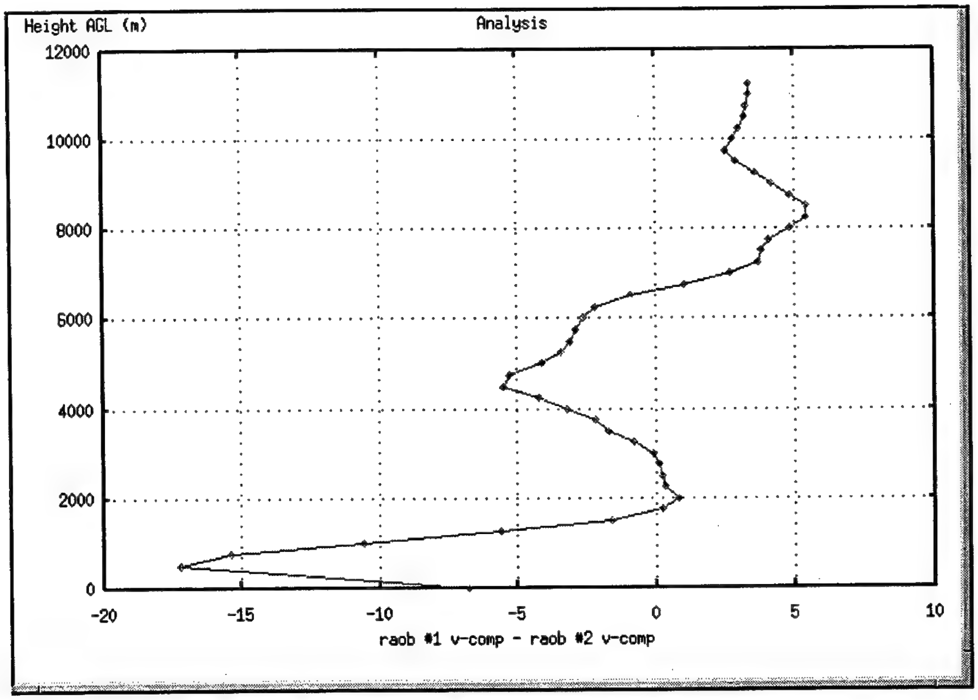


Figure 14. Tv deltas (deg K) for two 1200 UTC Santa Teresa, NM raobs, 9 August and 10 August 1999.

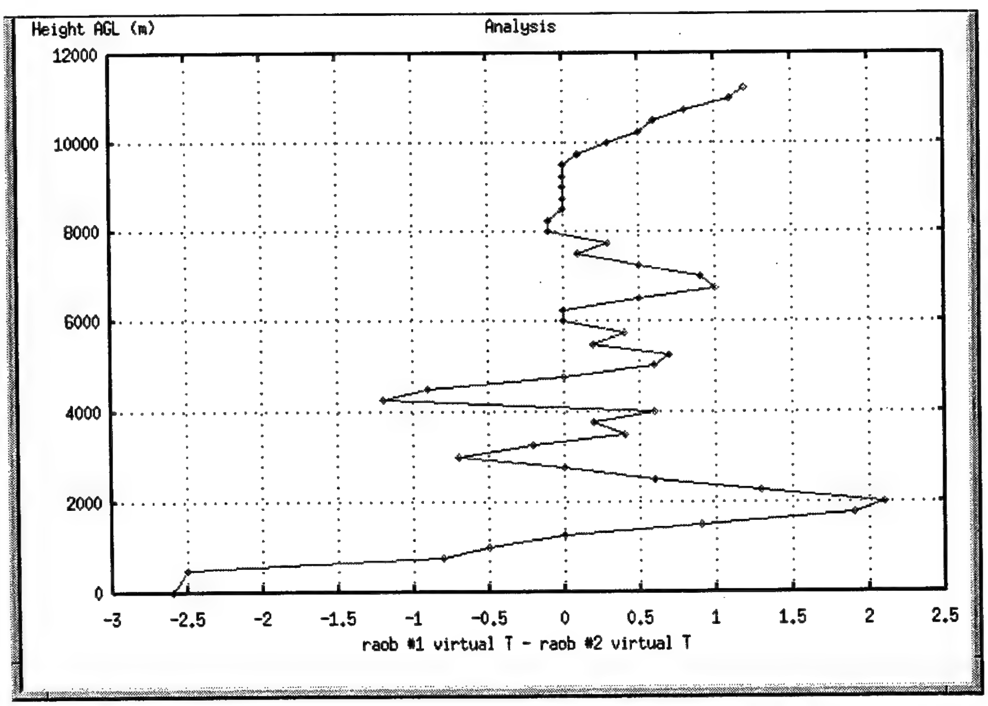
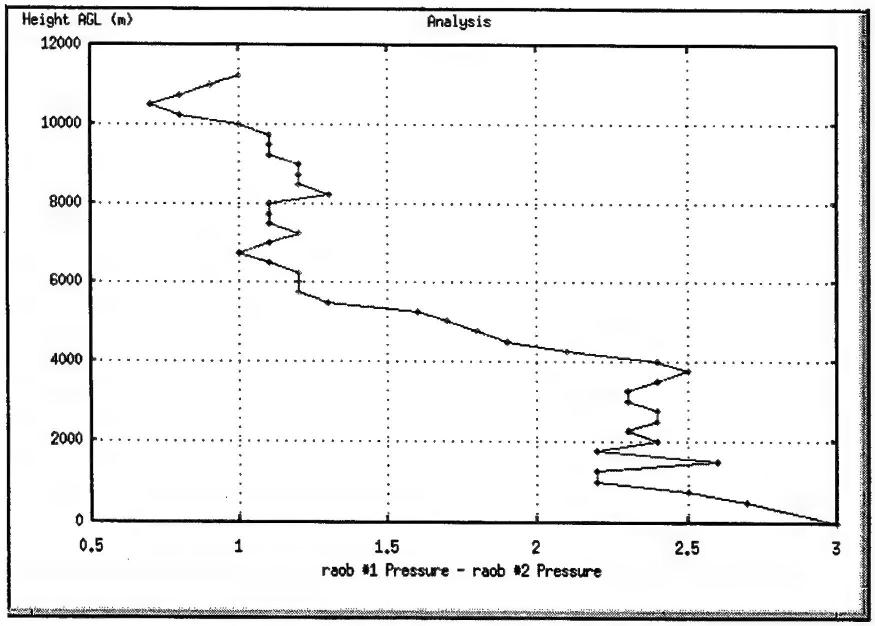


Figure 15. P deltas (mb) for two 1200 UTC Santa Teresa, NM raobs, 9 August and 10 August 1999.



3.4 Comparison of a CAAM BFM metcm (from a Model Run) with a MMS metcm

Figures 16-19 are graphical comparisons of the differences between a CAAM BFM model computation of u, v, Tv, and P as output in a metcm valid at Profiler site and the measurement of u, v, Tv, and P by a MMS balloon output in metcm format also valid at Profiler site.

Figure 16. U-component deltas (m/s) between CAAM metcm for Profiler site (valid 10 August 1999, 1200 UTC and MMS metcm (10 August 1999, 2200 UTC) for Profiler site.

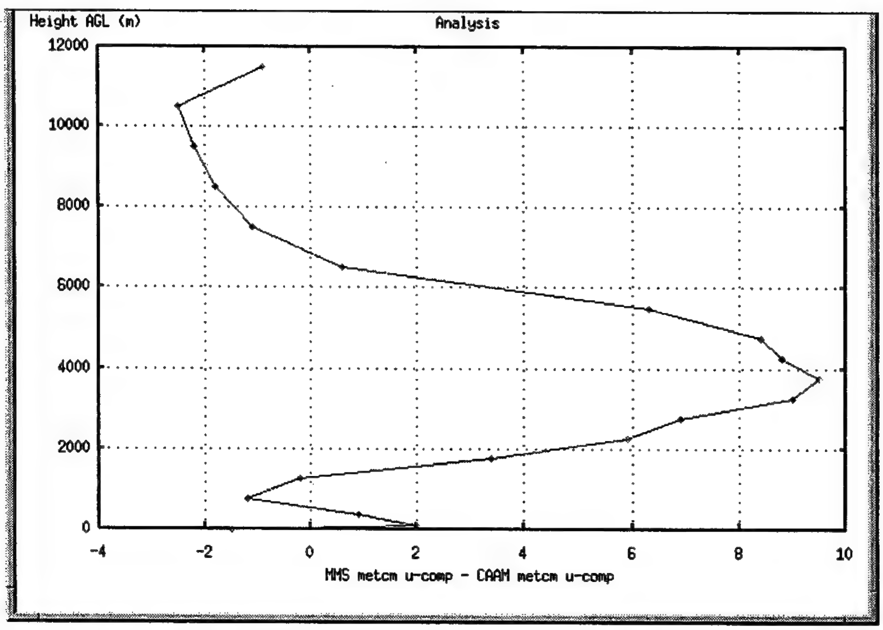


Figure 17. V-component deltas (m/s) between CAAM metcm for Profiler site (10 August 1999, 1200 UTC) and MMS metcm (10 August 1999, 2200 UTC) for Profiler site .

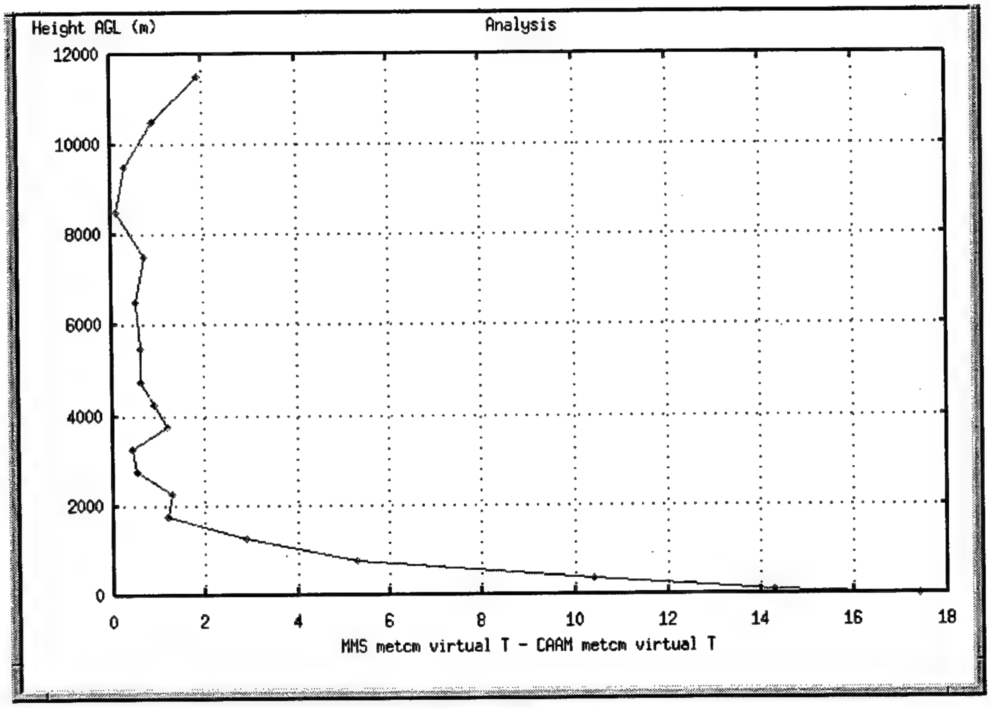


Figure 18. Tv deltas (deg K) between CAAM metcm for Profiler site (10 August 1999, 1200 UTC) and MMS metcm (10 August 1999, 2200 UTC) for Profiler site.

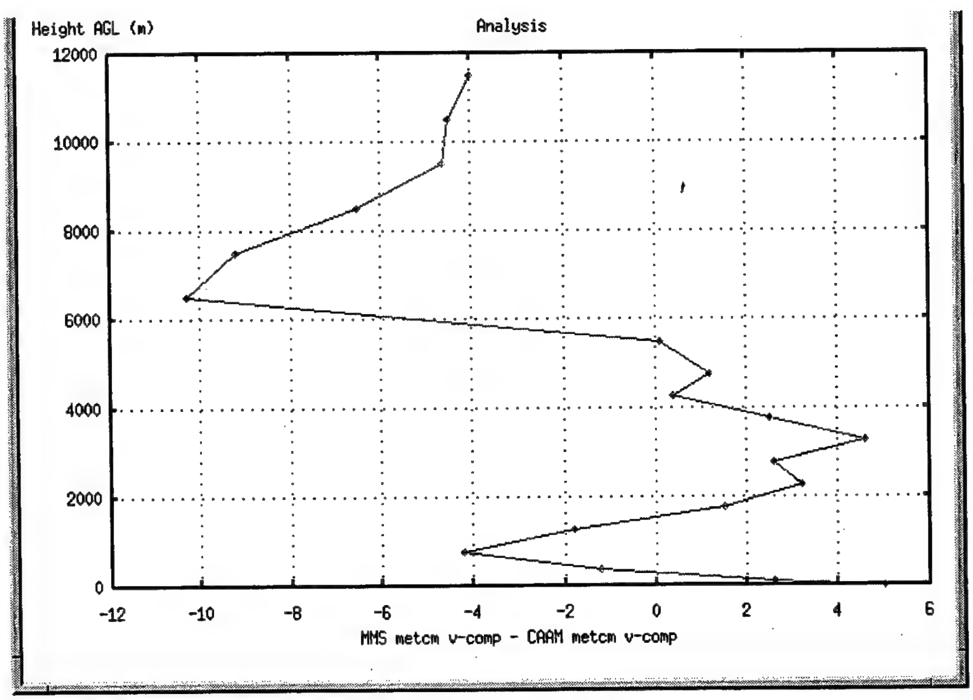
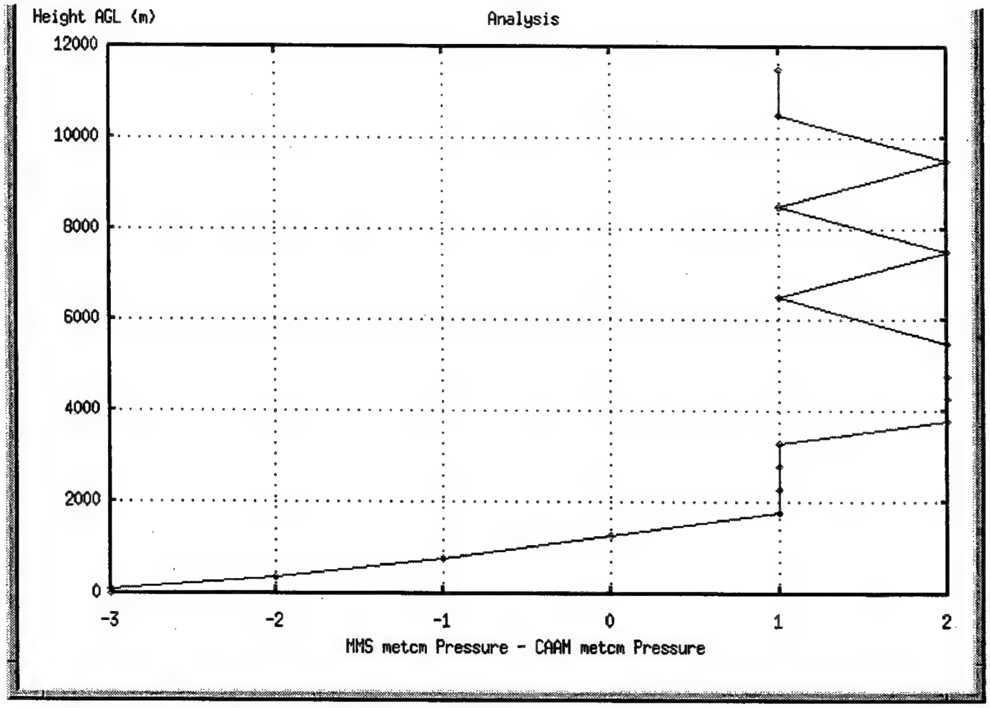


Figure 19. P deltas (mb) between CAAM metcm for Profiler site (valid 10 August 1999, 1200 UTC) and MMS metcm (10 August 1999, 2200Z) at Profiler site.



Note in figure 18 is the +17° K virtual temperature difference at the surface. The fact that the MMS raob is from mid-afternoon explains part of the difference. More specifically, the MMS surface temperature would be at the maximum heating portion of the day while the CAAM metcm is valid when there is maximum cooling at the surface. Above 2 km, the two systems agree very closely. In figure 19, the pressure differences are always within 2 mb.

3.5 Comparisons of a CAAM BFM metcm (from a Model Run) with like Data Displaced Either Spatially or Temporally or Both.

Figures 20-23 illustrate how the "stats" program can be utilized to compare the u, v, Tv, and P variables between two CAAM BFM metcms. Here, gnuplot displays data from CAAM BFM metcms valid at Profiler site and Santa Theresa, NM site for 10 Aug 1999, 1200 UTC.

Figure 20. U-component deltas (m/s) between CAAM metcms at Profiler site (10 August 1999, 1200 UTC) and Santa Teresa, NM site (10 August 1999, 1200 UTC).

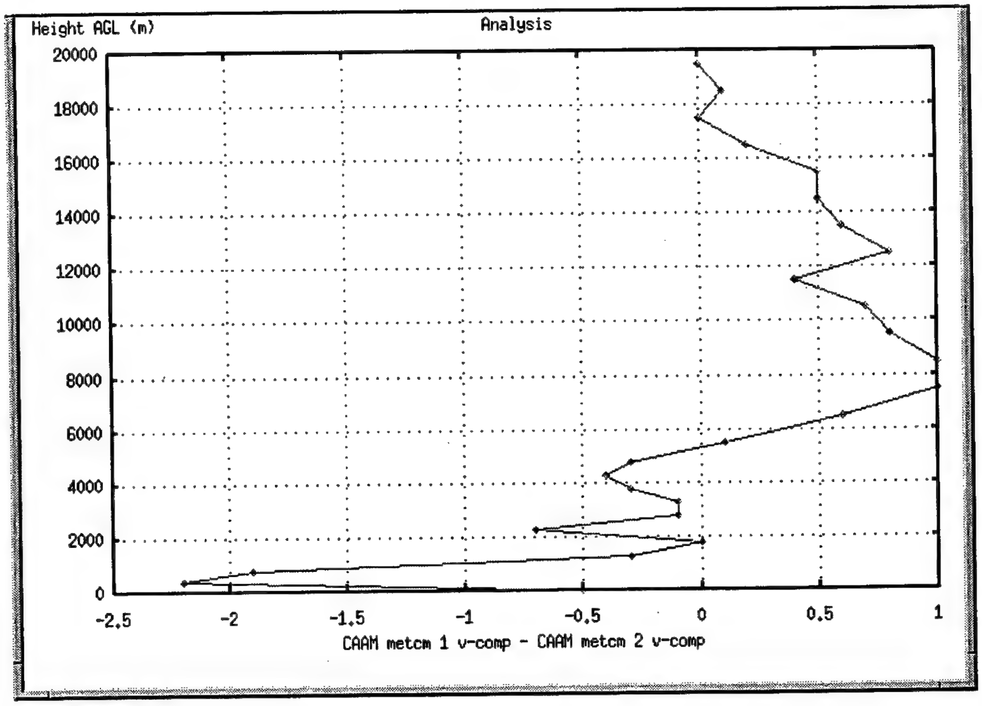


Figure 21. V-component deltas (m/s) between CAAM metcms at Profiler site (10 August 1999, 1200 UTC) and Santa Teresa, NM (10 August 1999, 1200 UTC).

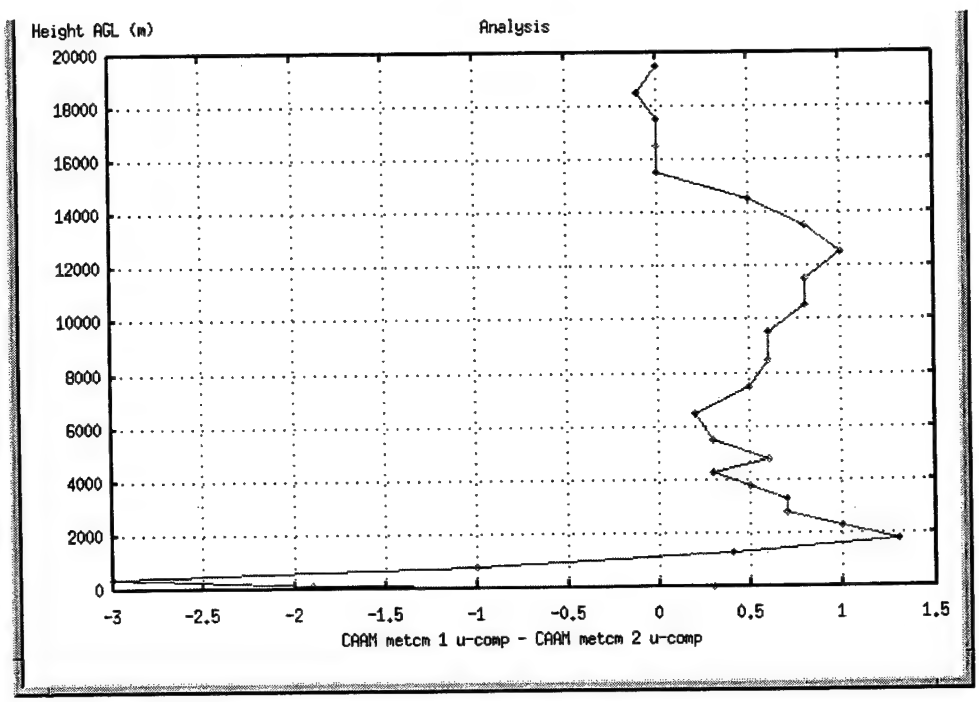


Figure 22. Tv deltas (deg K) between CAAM metcms at Profiler site (10 August 1999, 1200 UTC) and Santa Teresa, NM site (10 August 1999, 1200 UTC).

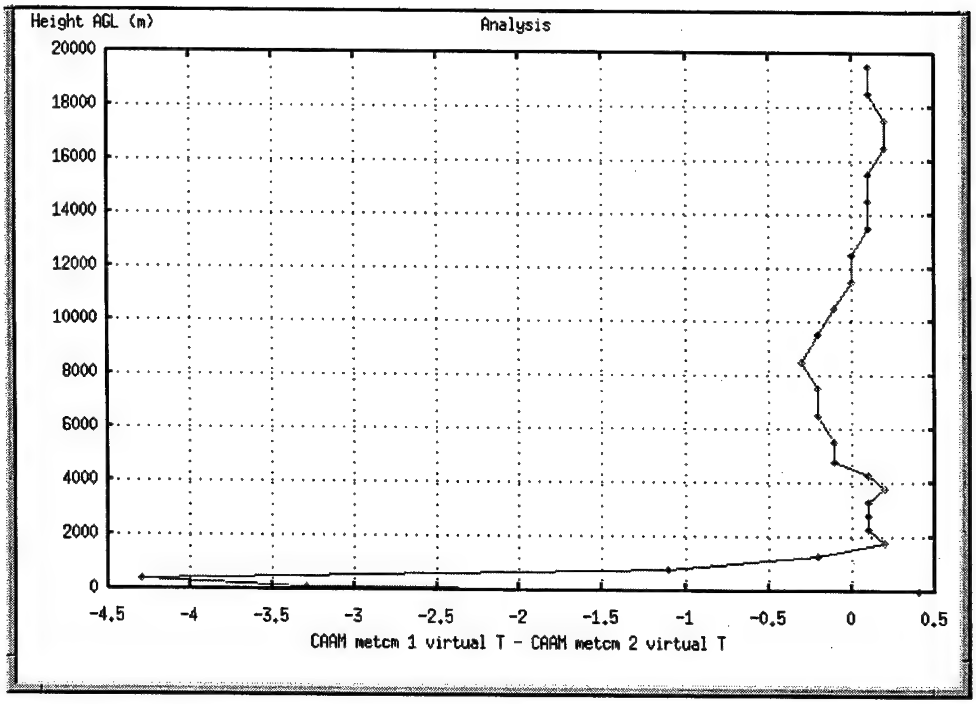
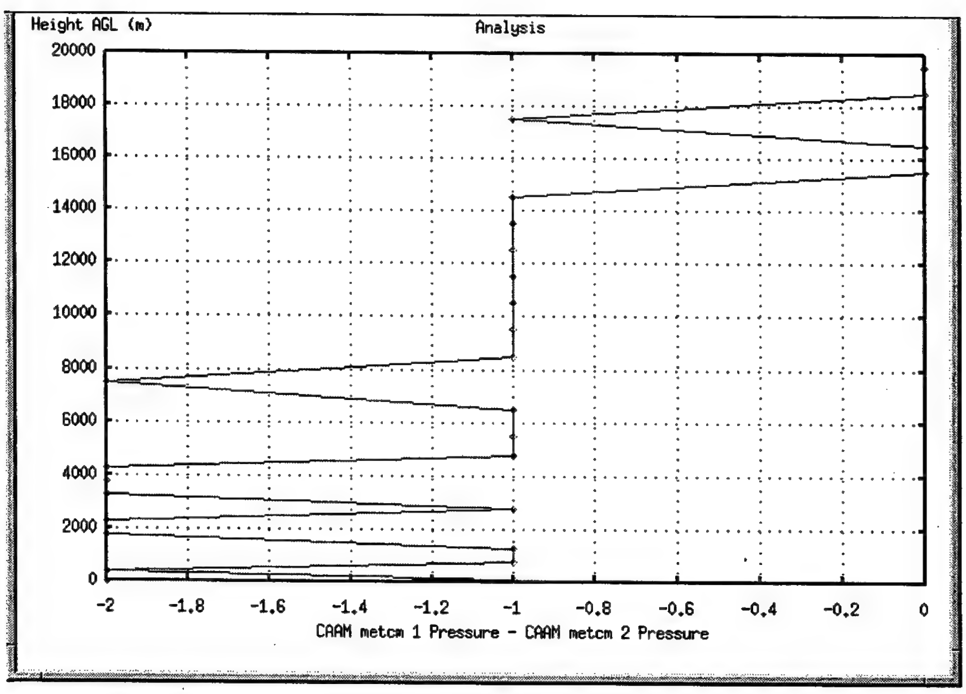


Figure 23. P deltas (mb) between CAAM metcms at Profiler site (10 August 1999, 1200 UTC) and Santa Teresa, NM site (10 August 1999, 1200 UTC).



As seen in previous cases, as one gets above the so-called boundary layer (at about 1 km) frictional effects become less important and stations in relatively close proximity in time and space show fairly good agreement in winds. Temperature gradients will decrease with height, as will the effects due to surface type differences. In addition, the local geography becomes less and less of a factor. These factors are evident here as well. In figure 20, above 2 km the u-component differences diminish significantly. The v-component displays the same characteristics. Temperature deltas are virtually zero above 2 km. The pressure deltas are again always within 2 mb.

4.0 Conclusions

The stats analysis and display software is potentially a useful tool for determining the accuracy of profiler data when used as input to the CAAM BFM mesoscale model. In addition, it can be used to compare two types of weather balloon data formats, the MMS and those such as from the NWS. Furthermore, metcms in either the MMS or CAAM BFM format can be compared. Thus anywhere the CAAM BFM model or MMS balloon data is being analyzed this software can be an asset.

Acronyms

AGL	above ground level
ARL	U.S. Army Research Laboratory
CAAM BFM	Computer-Assisted Artillery Meteorology Battlescale Forecast Model
metcm	computer meteorological message
MMS	Meteorological Measuring Set
MMS-P (POC)	Meteorological Measuring Set – Profiler (Proof-of-Concept)
MSL	mean sea level
NWS	National Weather Service
raob	radiosonde observation
rmse	root mean square error
UTC	Universal Time Coordinates

Appendix A

Software Module Description

i. stats

Description: A Bourne shell script. The user types "stats" at the UNIX prompt and a screen will be displayed giving the user 13 options:

1) Compare MMS raob, CAAM BFM "out.bin" data and display results with GNUPLOT
2) Compare MMS raob, CAAM BFM "out.bin" data and send output to default printer
3) Compare MMS raob, "NWS format" raob and display results with GNUPLOT
4) Compare MMS raob, "NWS format" raob and send output to default printer
5) Compare "NWS format" raob, CAAM BFM "out.bin" file and display results with GNUPLOT
6) Compare "NWS format" raob, CAAM BFM "out.bin" file and send output to default printer
7) Compare 2 "NWS format" raobs, display results with GNUPLOT
8) Compare 2 "NWS format" raobs, send results to default printer
9) Compare CAAM BFM metcm, MMS metcm and display results with GNUPLOT
10) Compare CAAM BFM metcm, MMS metcm and send results to default printer
11) Compare 2 CAAM BFM metcm's and display results with GNUPLOT
12) Compare 2 CAAM BFM metcm's and send results to default printer
13) Exit the stats program

ii. compare_raob_MMSraob.f

Description: Takes "NWS format" raob, MMS format raob, performs vertical interpolation of each to predefined heights.

Inputs:

a. NWS format raob
b. MMS raob
c. "z_zm.file" – heights at which the pseudo-terrain-following analysis is produced.
d. "terrain1.in" file – an ascii file containing gridded elevation data in meters. The file header contains the center point latitude/longitude (deg), the number of grid points in the x- and y-directions, and the grid spacing (m).

Outputs:

a. "raob_compare_raob1"
   Contains: latitude, longitude, height, u-, v-component, ambient and virtual temperature, and pressure
b. "raob_compare_raob2"
   Contains same information

iii. compare_raob_BFMout_bin.f

Description: For comparison of a "NWS format" raob and the particular forecast component of a CAAM BFM out.bin file. Performs

1) Bilinear interpolation (i.e. horizontal) of CAAM BFM gridded data to get values at the particular latitude/longitude of the raob being compared with.
2) Vertical interpolation of CAAM BFM data
3) Vertical interpolation of NWS format raob

Inputs:

a. "NWS format" raob
b. CAAM BFM "out.bin" file
c. "z_zm.file"
d. "terrain1.in" file

Outputs:

a. "compare_raob"
   contains: latitude, longitude, u-, v-component, ambient and virtual temperature, and pressure
b. "compare_model"
   contains: same information

iv. compare_raob1_raob2.f

Description: Takes two "NWS format" raobs and vertically interpolates each raob to predefined heights. In order to calculate virtual temperature, an intermediate variable, Q (mixing ratio), is defined as a function of pressure and dew point temperature.

Inputs:

a. "z_zm.file"
b. "terrain1.in" file
c. two "NWS format" raobs

Outputs:

a. "raob_compare_raob1"
   contains: latitude, longitude, u-, v-component, ambient and virtual temperature, and pressure
b. "raob_compare_raob2"
   contains: same information

v. *parseInternetRaob.c*

Description: By searching out certain keywords and positions in the input file, extracts and writes to the output file the variables: Pressure, height, ambient and dew point temperature, wind speed and direction.

Input:

a. "NWS format" raob

Output:

a. "Internet_raob_reformatted"

vi. *parseMMS.c*

Description: Sifts through the input file by looking for keywords and certain positions in the file to extract the variables: pressure, height, ambient and dew point temperature, wind speed and direction.

Input: MMS raob

Output: "MMS_raob_reformatted"

vii. *reformat_mms_metcm.c*

Description: Takes a MMS computer meteorological message which has multiple levels of data per line of wind direction and speed, virtual temperature and pressure.

Input: MMS metcm

Output: "colformat_mms_metcm"

viii. reformat_bfm_metcm_to_columns.c

Description: Takes a CAAM BFM computer meteorological message which has 3 levels per line of wind direction and speed, virtual temperature, and pressure.

Input: CAAM BFM metcm

Output: "colformat_bfm_metcm"

ix. rd_raob_compare.c

Description: Assuming "good" values for the variables, u- and v-component, virtual temperature, and pressure at matching heights in the raobs, outputs the differences at each height level.

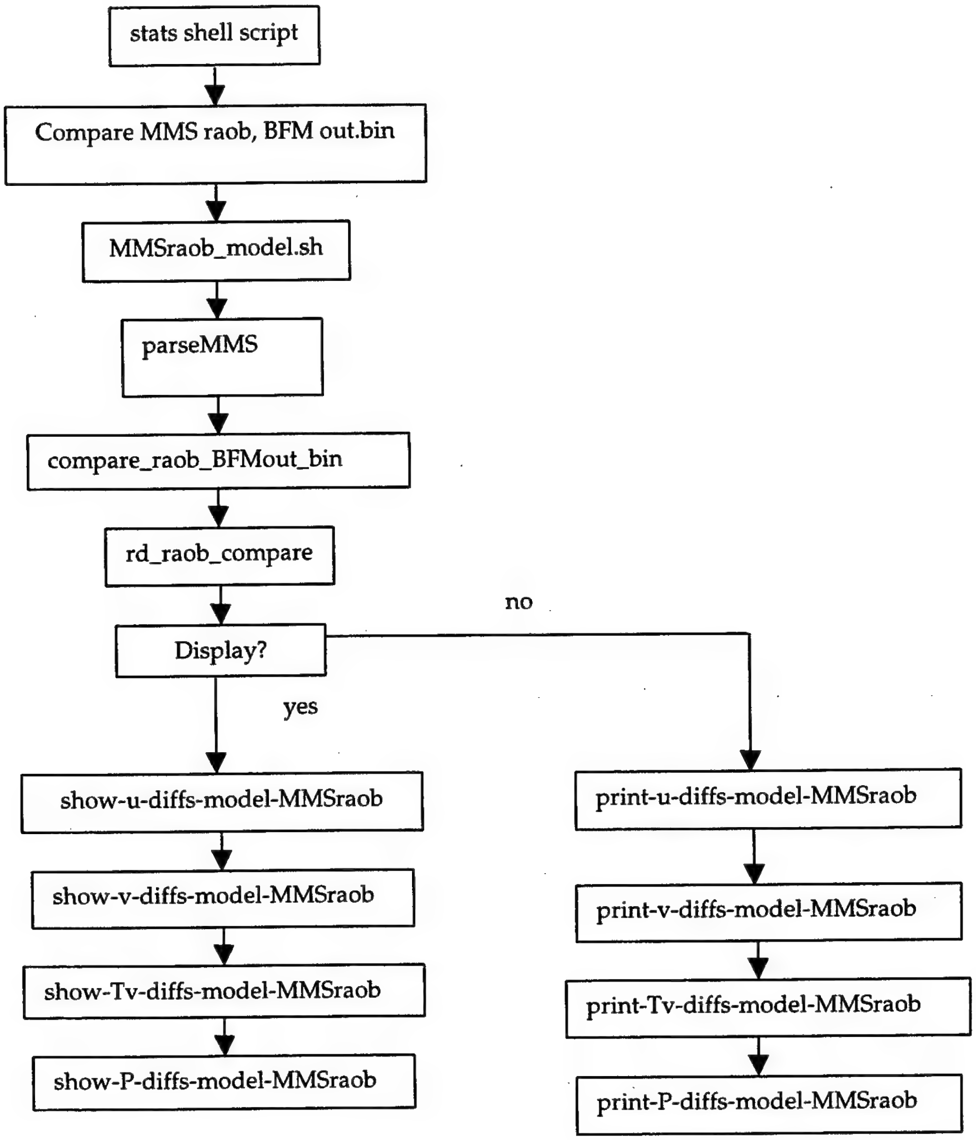
Inputs: two raobs as output by 1 of the aforementioned FORTRAN programs

Output: "compare_raob_rmse" containing root mean square errors in the u- and v-component, virtual temperature, and pressure

Appendix B

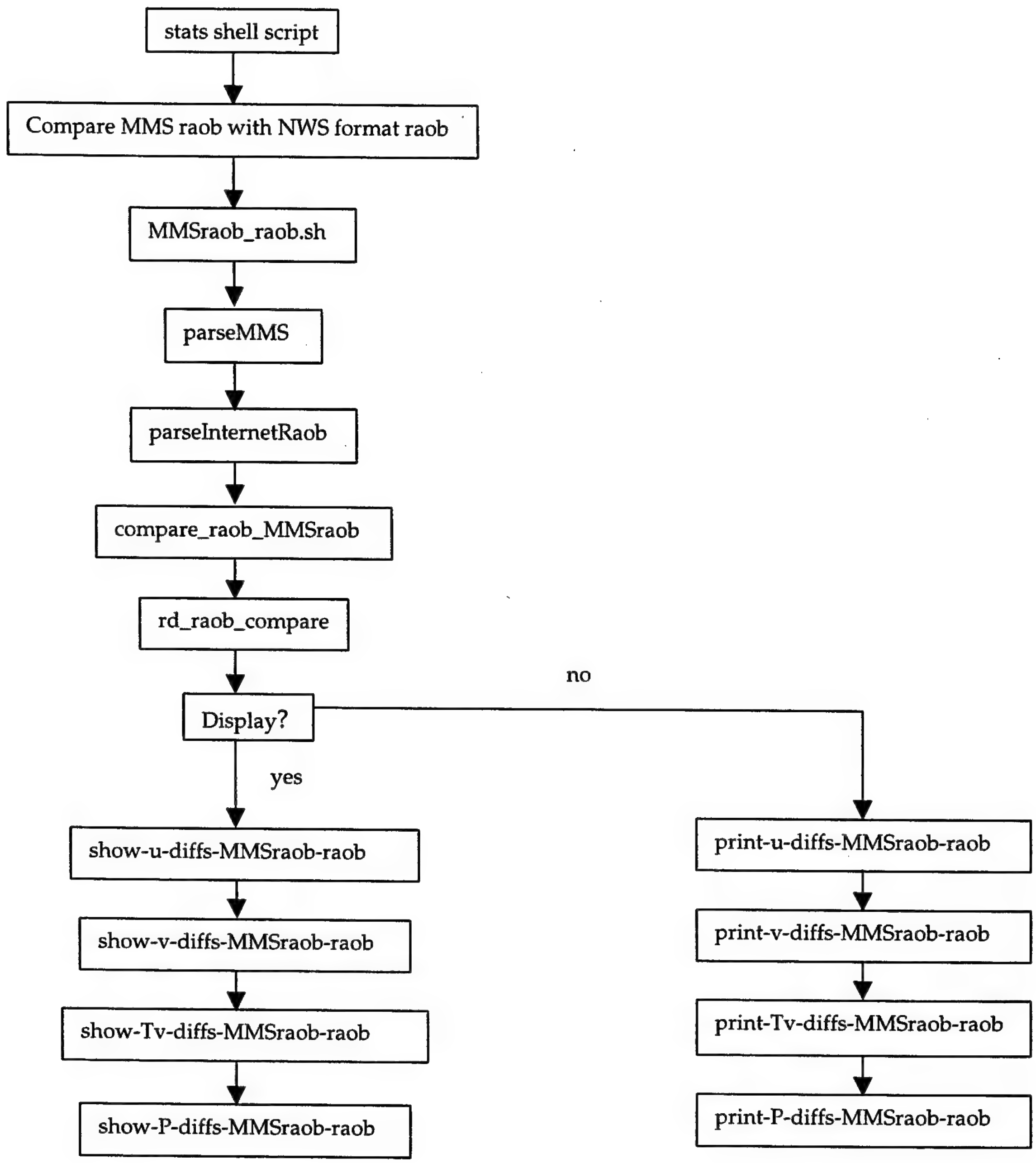
Program Flow Chart

i. stats options 1 and 2

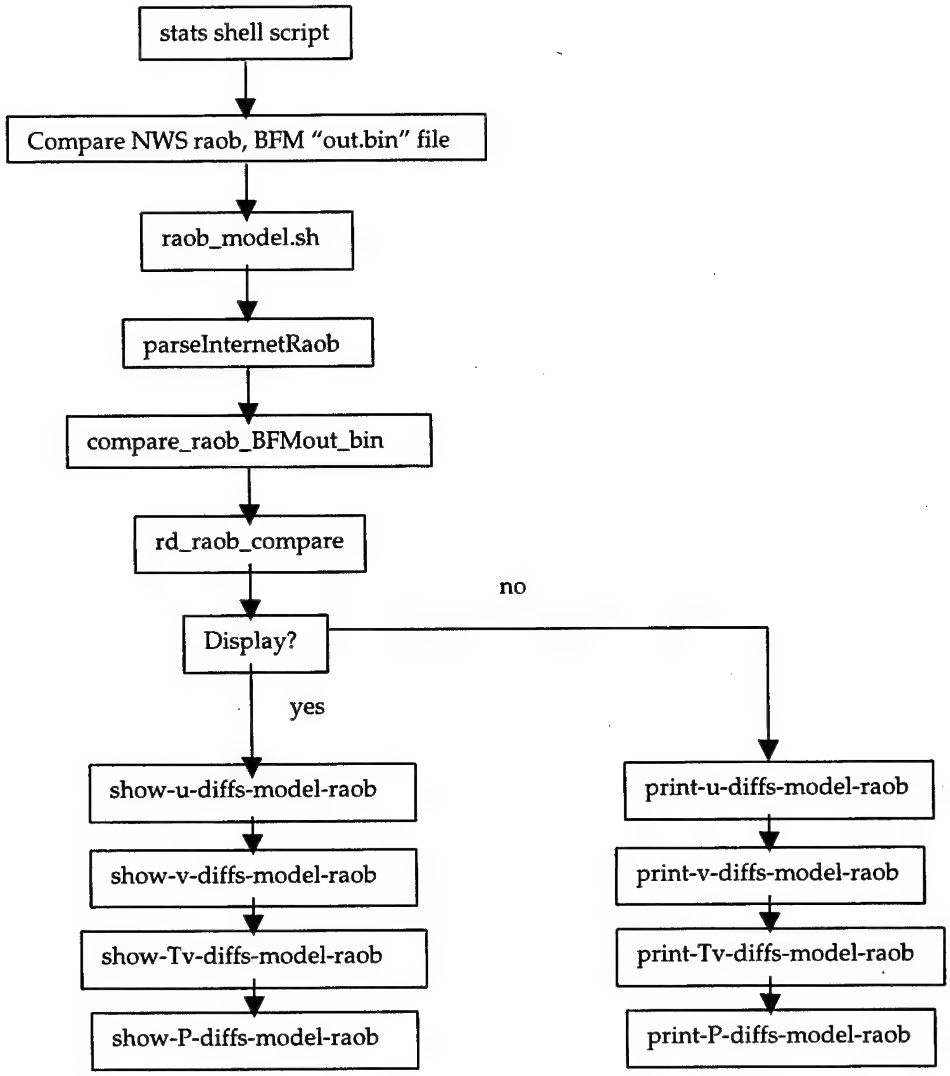


Note: It is within the "show-..." and "print-..." executables that GNUPLOT is called.

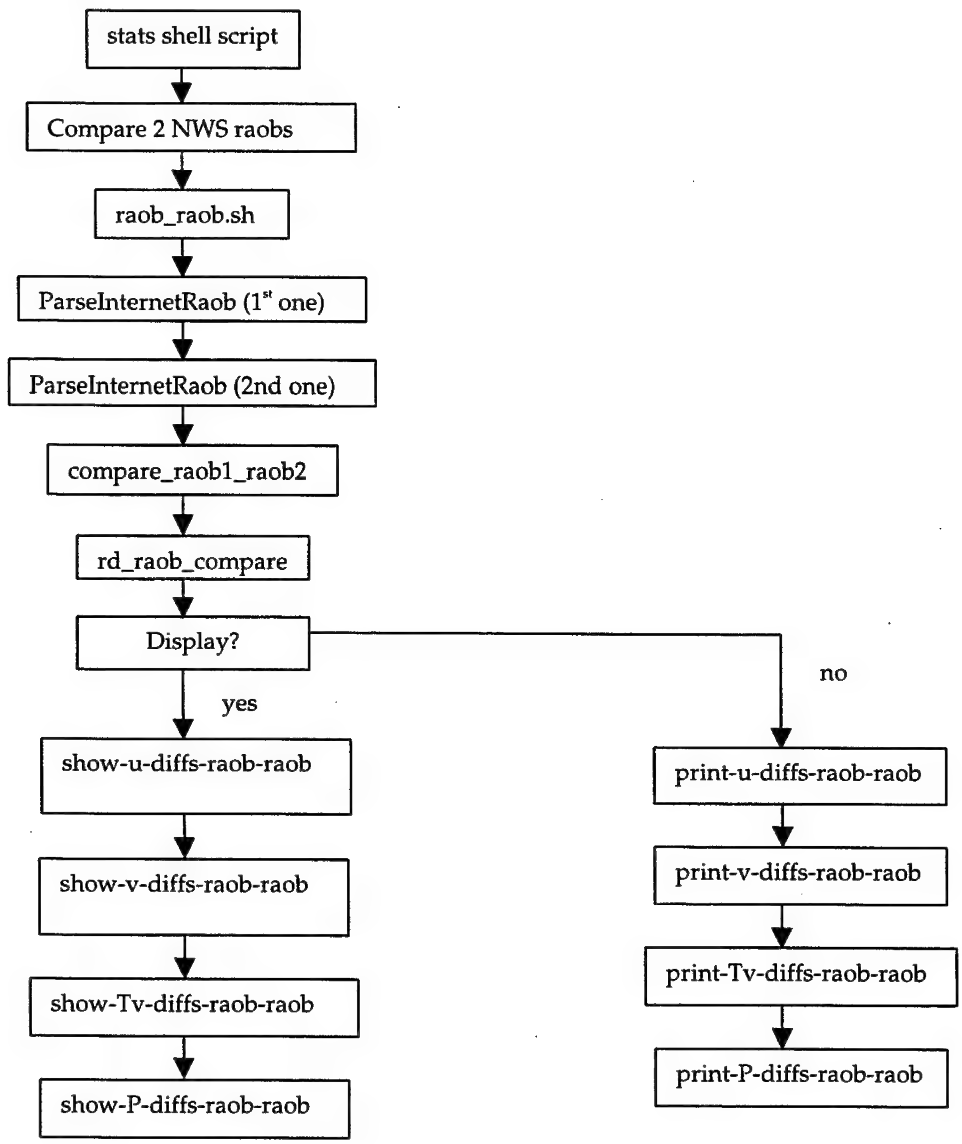
ii. stats options 3 and 4



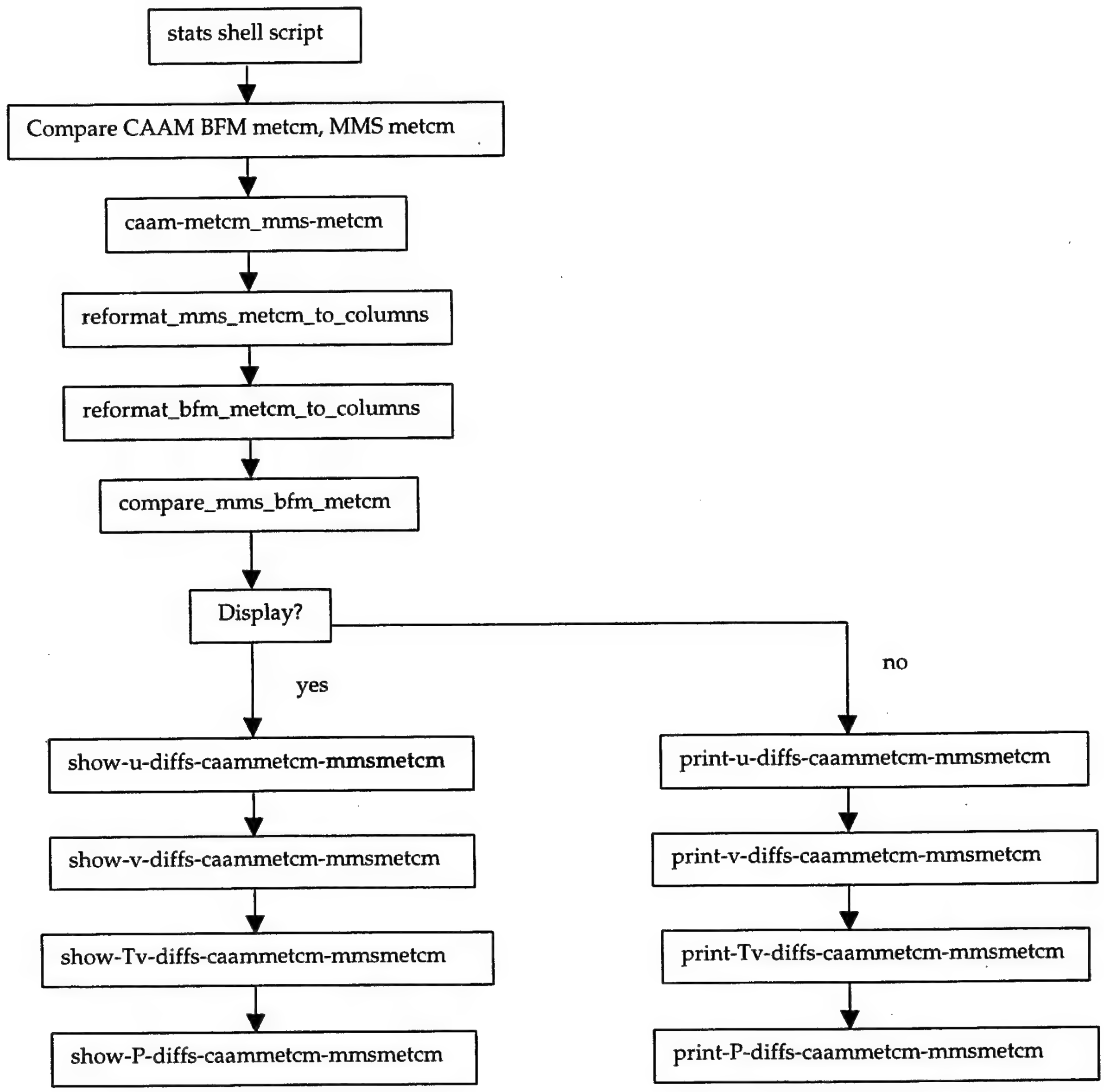
iii. stats options 5 and 6



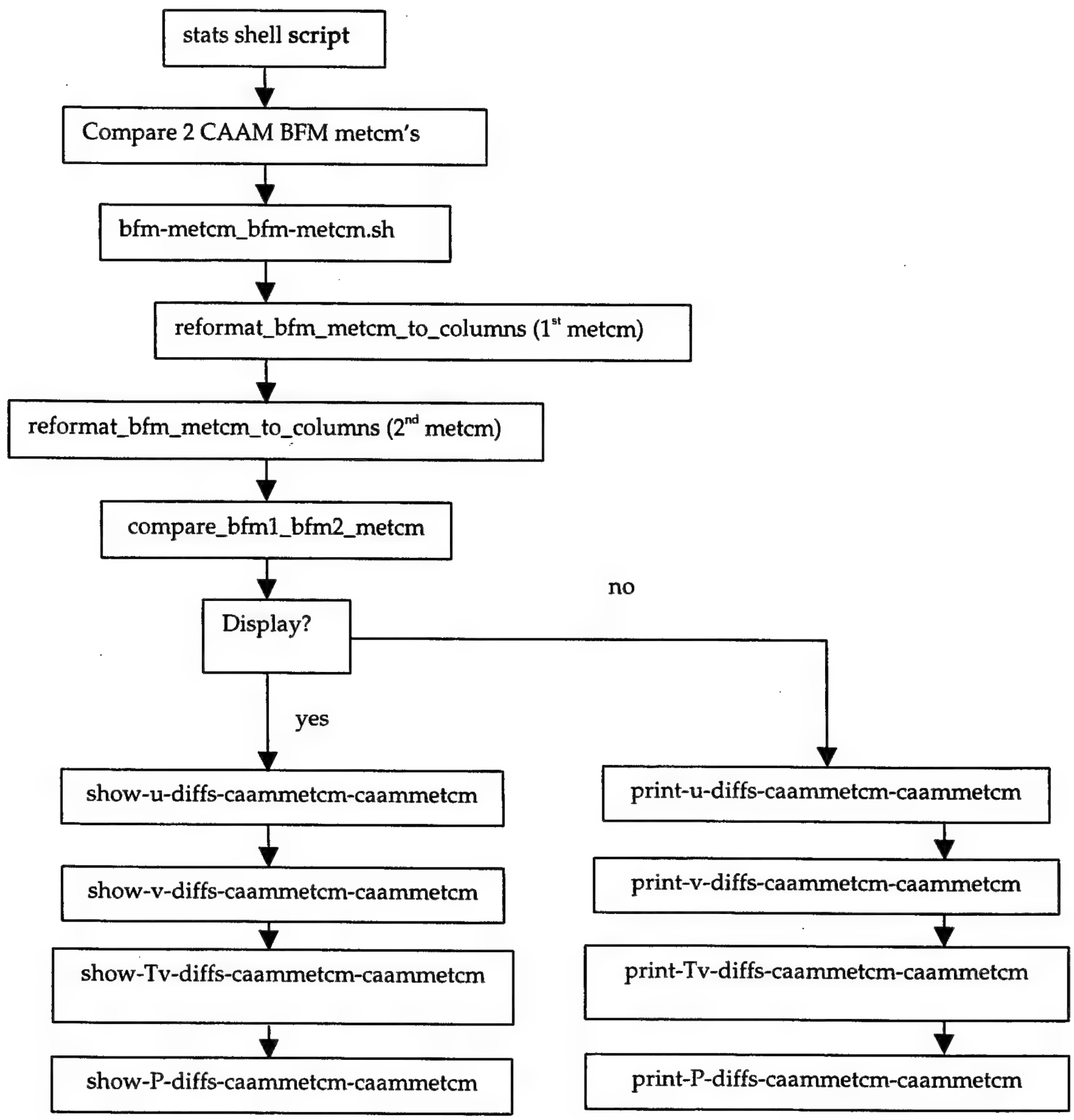
iv. stats options 7 and 8



v. stats options 9 and 10



vi. stats options 11 and 12



Appendix C

A Sample GNUPLOT file

In this particular case a postscript file is created. To change it to screen display one would remove the *set terminal* line and the *set output* line.

```
set terminal postscript
#show terminal
set autoscale
set output "u_MMS_raob.ps"
set grid
set title 'Analysis'
set xlabel 'MMS u-comp - raob u-comp'
#set xtics 0, 2, 50
#set xrange[0 : 50]
#set xtics -30, 2, 30
#set xrange[-30 : 30]
set ylabel 'Height AGL (m)' 2,0
#set ytics 0, 1000, 20000
#set yrange [0 : 20000]
#set size 0.66, 0.8
#set label 1 "raob Tv" at 283., 2250.
#next plot diffs in u and v respectively
#plot "mms_bfm_diffs" using 3:2 notitle  with linespoints 1 1
#pause -1
plot "compare_raob_delta_u_filtered" using 2:1 notitle  with
linespoints 1 1
```

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